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SUBJECT: US EPITAXIAL REACTORS TO THE USSR--IL 1355

REF: A) COCOM DOC (77) 887, B) PARIS 101,
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1.
THE US GOVERNMENT REVIEW OF THESE APPLICATIONS DID CONSIDER THE POSSIBLE USE OF THE MACHINES FOR SILICON EPITAXY WORK. SILICON BIPOLAR DEVICES, ESPECIALLY MICRO-WAVE DEVICES, REQUIRE A VERY THIN EPITAXIAL LAYER, ON THE ORDER OF ONE MICRON THICK, DEPOSITED BY EPITAXIAL REACTORS CAPABLE OF CLOSE CONTROL OVER DEPOSITION TIMES (0-20 SECOND RANGE), LAYER UNIFORMITY AND THICKNESS (BETTER THAN 10 PER-CENT) AND CHEMICAL FLOW. REVIEW CONCLUSIONS WERE THAT IF THE REACTORS COULD BE CONVERTED, THEY WOULD ALSO REQUIRE UPGRADING OF THE CONTROL SYSTEMS. THIS WAS DETERMINED TO
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BE UNLIKELY.

2. US GOVERNMENT TECHNICIANS FOUND FROM THEIR STUDY THAT USE OF MACHINES FOR SILICON OR THE CONVERSION OF THE MACHINES TO SILICON EPITAXY WAS NOT FEASIBLE. THE REACTOR FALLS UNDER THE GENERAL CLASSIFICATION OF A HOT WALL REACTOR SYSTEM IN CONTRAST TO THE COLD WALL SYSTEM USED

FOR SILICON EPITAXIAL DEPOSITION. THIS DISTINCTION ARISES FROM THE BASIC DIFFERENCE IN THE CHEMISTRY OF THE PROCESSES USED FOR GALLIUM ARSENIDE PHOSPHIDE EPITAXY RELATIVE TO SILICON. THE LED PROCESS SEQUENCE CONSISTS OF THREE CHEMICAL REACTIONS IN SERIES.

1) HC1 PLUS GA ---T1--- GAC1 PLUS 1/2 H2
2) GAC1 PLUS (X)PH3 PLUS (Y) ASH3 ---T2 --- INTERMEDIATE SPECIES
3) INTERMEDIATE SPECIES ...T3--- GAASYPX PLUS HC1

3.REACTION (1) OCCURS AT THE HIGHEST TEMPERATURE, (2) AT AN INTERMEDIATE VALUE AND (3) AT THE LOWEST. TYPICALLY T1 EQUALS 950 DEGREES C, T2 EQUALS 850 DEGREES C, AND T3 EQUALS 750 DEGREES C. SINCE THE REACTION PROCEEDS IN THE DIRECTION OF THE LOWEST TEMPERATURE, THE SURFACES DEFINING THE REACTION SPACE ARE NECESSARILY MAINTAINED AT A HIGHER TEMPERATURE. IN THIS WAY, THE DEPOSITION PROCESS IS DIRECTED TOWARD THE SUBSTRATE WAFERS UPON WHICH THE EPITAXIAL FILM IS DESIRED TO BE GROWN. IN THE REACTOR THIS REACTION SPACE DEFINING SURFACE IS THE CYLINDRICAL GRAPHITE CYLINDER MOUNTED INTERNAL TO THE BELL JAR AND HEATED BY RF INDUCTION. BY SPATIALLY VARYING THE POWER INPUT INTO THIS GRAPHITE CYLINDER THE DESIRED THREE REACTION ZONES, EACH AT A DIFFERENT TEMPERATURE, ARE OBTAINED.
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4. IN CONTRAST, THE EPITAXIAL GROWTH OF SILICON OCCURS VIA A SIMPLE HIGH TEMPERATURE REDUCTION PROCESS. IN THE CASE OF GROWTH FROM SILICON TETRACHLORIDE, THE REACTION IN MOST COMMON USE, THE REACTION IS:

SIC14 PLUS 2H2 ---T1--- SI PLUS 4HC1

5. THE REACTION OCCURS AS THE REACTING SPECIES APPROACH THE REACTION TEMPERATURE, TYPICALLY ABOVE 1000 DEGREES C. THIS IS TO SAY THE DEPOSITION REACTION MOVES IN THE DIRECTION OF THE HIGHEST TEMPERATURE. FOR THIS REA-SON, EPITAXIAL SILICON REACTOR SYSTEMS ARE OF THE COLD WALL DESIGN. IN THIS WAY, THE REACTION IS DIRECTED AWAY FROM THE CHAMBER WALLS AND TOWARD THE SUBSTRATE WAFERS WHICH ARE PLACED AT THE HOTTEST POINT IN THE SYSTEM. IT IS COMMON PRACTICE THAT RF INDUCTION IS USED TO HEAT A GRAPHITE PLATE, CALLED A SUSCEPTOR, UPON WHICH THE SUBSTRATE WAFERS ARE PLACED. THE QUARTZ WALLS DEFINING THE REACTION SPACE ARE UNHEATED AND ARE TYPICALLY COOLED BY A FLOW OF AIR.

THE SEVERAL DIFFERENCES BETWEEN A REACTOR SYSTEM FOR LED EPITAXIAL GROWTH AND SILICON EPITAXY MAY BE SUMMARIZED AS FOLLOWS:

1) LED EPITAXY REQUIRES A HOT WALL SYSTEM; SILICON EPITAXY A COLD WALL.

2) LED EPITAXY NEEDS A MULTI-TERMPERATURE ZONE REACTION SPACE; SILICON EPITAXY A SINGLE, UNIFORM HIGH TERMPERATURE DEPOSITION ZONE.

3) LED EPITAXY OPERATES OVER A TEMPERATURE RANGE OF 750 TO 950 DEGREES C; SILICON EPITAXY IS CONDUCTED TYPICALLY AT 1050 TO 1250 DEGREES C. IN VIEW OF CONFIDENTIAL

THE HIGHER TEMPERATURE AND THE HIGHER HEAT LOSSES (THE COLD WALL REACTOR DESIGN), SILICON EPITAXY REQUIRES A HIGHER POWER INPUT TO THE REACTOR, I.E., A LARGER RF GENERATOR.

7. IN ADDITION TO THESE CONSIDERATION, THE REACTION EPITAXIALLY DEPOSITING GALLIUM ARSENIDE PHOSPHIDE IS A SURFACE RATE CONTROLLED REACTION. AS SUCH, THE RATE OF DEPOSITION IS A FUNCTION ONLY OF THE SUBSTRATE TEMPERATURE, SUBSTRATE CRYSTAL ORIENTATION, AND REACTANT CONCENTRATIONS IN THE BULK GAS PHASE. GAS FLOWS, FLOW VELOCITIES, AND FLOW DIRECTION ARE NOT CRITICAL PARAMETERS IN OBTAINING UNIFORM GROWTH. IN CONTRAST, SILICON EPITAXY IS, TO A SIGNIFICANT DEGREE, A FUNCTION OF THE RATE OF MASS TRANSFER OF REACTANTS TO THE WAFER SURFACE. FOR THIS REASON, THE METHOD OF GAS FLOW OVER THE SURFACE BECOMES A CRITICAL FACTOR IN DETERMING GROWTH UNIFORMITY. THIS DIFFERENCE IN OVERALL REACTION MECHANISM HAS CONTRIBUTED TO THE VERY LARGE DIFFERENCE IN CONFIGURATION OF LED AND SILICON EPITAXIAL REACTORS.

9. FOR THESE REASONS, CONVERSION OF THE LED REACTOR INTO A SILICON EPITAXIAL REACTOR OWULD, AT A MINIMUM, REQUIRE REPLACEMENT OF THE ENTIRE REACTOR CHAMBER, RESIZING OF THE CHEMICAL PLUMBING, AND METERING JETS FOR THE NEW CHEMICALS, AND DEVELOPMENT OF A TOTALLY NEW HEATING RF SYSTEM; A VERY DIFFICULT TASK. IT WOULD BE FAR EASIER TO CONSTRUCT A SILICON EPITAXIAL REACTOR FROM SCRATCH.

9. SILICON CONSIDERATIONS ASIDE, THE US CONCERN OVER MODIFICATION AND DIVERSION TO THE MANUFACTURE OF GALLIUM COMPOUND MICROWAVE DEVICES WAS ALSO ALLAYED THROUGH THE EMPLOYMENT OF A MAINTENANCE CONTRACT. THIS IS AN EFFEC-

TIVE DIVERSION DETERRENT BECAUSE THE EQUIPMENT IS VERY COMPLEX AND NEEDS EXPERT MAINTENANCE GENERALLY BEYOND THE TECHNICAL SCOPE OF A PURCHASER, EITHER US OR FOREIGN. INDEED, THE SOVIETS INSISTED UPON HAVING A MAINTENANCE AGREEMENT BETWEEN THE US EQUIPMENT MANUFACTURER AND THE SOVIET PURCHASER. THIS CONTRACT REQUIRES THE US FIRM TO NOT ONLY INSTALL THE REACTORS BUT TO ALSO PROVIDE EQUIPMENT MAINTENANCE, AT LEAST ONCE EVERY 6 MONTH PERIOD, AT THE SOVIET SITE. US PRESENCE AT THE RUSSIAN PLANT WILL NOT ONLY VERIFY CONFORMANCE TO THE STATED END USE, BUT WILL REVEAL ANY EQUIPMENT MODIFICATION OR REMOVAL. OVERALL US EXPERIENCE HAS SHOWN THAT WITHOUT CONTINUING MACHINE REPAIR AND COMPONENT SUPPLY SUPPORT FROM THE US MANUFACTURER, THE MACHINES CANNOT SATISFACTORILY FUNCTION FOR MORE THAN 6 MONTHS. THEREFORE, IT IS SUBMITTED THAT EVIDENCE OF DIVERSION WOULD RESULT IN REMOVAL OF U.S. SUPPORT WHICH WOULD RENDER THE REACTORS INEFFECTIVE AFTER A SHORT PERIOD OF TIME.

10. IN SUMMARY, THE US IS CONVINCED THAT THE RISK OF THE REACTORS BEING DIVERTED TO MICROWAVE MATERIAL PROCESSING IS MINIMAL BECAUSE EITHER THE MACHINE IS UNSUITED FOR PROCESSING THE MATERIAL, SILICON, OR THE VERY COMPLEXITY OF THE EQUIPMENT REQUIRES SOVIET DEPENDENCY ON A CONTINUING US PRESENCE AT THE EQUIPMENT SITE. THE ABILITY OF US TO DETECT MACHINE MISUSE IN THIS CASE IS CONSIDERED AN EFFECTIVE DETERRENT TO SOVIET DIVERSION. FINALLY NOTE THAT THE MACHINES MUST OBVIOUSLY BE MODIFIED BEFORE ANY ATTEMPTS TO PROCESS MICROWAVE MATERIAL MAY BE MADE AND SUCH ATTEMPTS IMMEDIATELY PRESENT THE OPPORTUNITY FOR US DETECTION. VANCE

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